



Prepared in cooperation with the
USDA Forest Service
U.S. Bureau of Land Management
U.S. Environmental Protection Agency

Integrated Investigations of Environmental Effects of Historical Mining in the Animas River Watershed, San Juan County, Colorado



Professional Paper 1651

U.S. Department of the Interior
U.S. Geological Survey

Cover. Red Mountains #1 through #3, viewed left to right looking east from the USDA Forest Service information stop near Red Mountain Pass, Colorado, September 2003. The colors of these red mountains illustrate the extent of alteration within the Silverton caldera that is responsible for the ore deposits and that also affects the water quality of streams. The panorama is digitally stitched (Briant A. Kimball).

Integrated Investigations of Environmental Effects of Historical Mining in the Animas River Watershed, San Juan County, Colorado

Edited by Stanley E. Church, Paul von Guerard, and Susan E. Finger

Prepared in cooperation with the
U.S. Department of Agriculture (USDA) Forest Service
U.S. Bureau of Land Management
U.S. Environmental Protection Agency

The Animas River watershed study comprises two volumes.
Volume 1 contains Chapters A, B, C, D, and E1–E10.
Volume 2 contains Chapters E11–E25, F, and G,
and an accompanying CD-ROM

Volumes 1 and 2

Professional Paper 1651

U.S. Department of the Interior
U.S. Geological Survey

U.S. Department of the Interior
DIRK KEMPTHORNE, Secretary

U.S. Geological Survey
Mark D. Myers, Director

U.S. Geological Survey, Reston, Virginia: 2007
First printing: 2007

For product and ordering information:
World Wide Web: <http://www.usgs.gov/pubprod>
Telephone: 1-888-ASK-USGS

For more information on the USGS--the Federal source for science about the Earth, its natural and living resources,
natural hazards, and the environment:
World Wide Web: <http://www.usgs.gov>
Telephone: 1-888-ASK-USGS

Any use of trade, product, or firm names is for descriptive purposes only and does not imply endorsement by the
U.S. Government.

Although this report is in the public domain, permission must be secured from the individual copyright owners to
reproduce any copyrighted materials contained within this report.

Suggested citation:
Church, S.E., von Guerard, Paul, and Finger, S.E., eds., 2007, Integrated investigations of environmental effects of
historical mining in the Animas River watershed, San Juan County, Colorado: U.S. Geological Survey Professional
Paper 1651, 1,096 p. plus CD-ROM. [In two volumes.]

Contents

Volume 1

A.	Summary and conclusions from investigation of the effects of historical mining in the Animas River watershed, San Juan County, Colorado.....	1
	By U.S. Geological Survey	
B.	The Animas River watershed, San Juan County, Colorado	17
	By Paul von Guerard, Stanley E. Church, Douglas B. Yager, and John M. Besser	
C.	History of mining and milling practices and production in San Juan County, Colorado, 1871–1991	39
	By William R. Jones	
D.	Impacts of historical mining on aquatic ecosystems—An ecological risk assessment.....	87
	By John M. Besser, Susan E. Finger, and Stanley E. Church	
E.	Watershed-Scale Characterization and Investigation of Processes Responsible for Environmental Effects of Historical Mining	
E1.	Geologic framework.....	107
	By Douglas B. Yager and Dana J. Bove	
E2.	Imaging spectroscopy applied to the Animas River watershed and Silverton caldera.....	141
	By J. Bradley Dalton, Dana J. Bove, Carol S. Mladinich, and Barnaby W. Rockwell	
E3.	Major styles of mineralization and hydrothermal alteration and related solid- and aqueous-phase geochemical signatures	161
	By Dana J. Bove, M. Alisa Mast, J. Bradley Dalton, Winfield G. Wright, and Douglas B. Yager	
E4.	Helicopter electromagnetic and magnetic surveys.....	231
	By Bruce D. Smith, Robert R. McDougal, Maryla Deszcz-Pan, and Douglas B. Yager	
E5.	Mine inventory and compilation of mine-adit chemistry data	255
	By Stanley E. Church, M. Alisa Mast, E. Paul Martin, and Carl L. Rich	
E6.	Mine adits, mine-waste dumps, and mill tailings as sources of contamination	311
	By J. Thomas Nash and David L. Fey	
E7.	Characterization of background water quality	347
	By M. Alisa Mast, Philip L. Verplanck, Winfield G. Wright, and Dana J. Bove	
E8.	Aqueous-sulfate stable isotopes—A study of mining-affected and undisturbed acidic drainage	387
	By D. Kirk Nordstrom, Winfield G. Wright, M. Alisa Mast, Dana J. Bove, and Robert O. Rye	
E9.	Quantification of metal loading by tracer injection and synoptic sampling, 1996–2000	417
	By Briant A. Kimball, Katherine Walton-Day, and Robert L. Runkel	
E10.	Distribution of pH values and dissolved trace-metal concentrations in streams.....	497
	By Winfield G. Wright, William Simon, Dana J. Bove, M. Alisa Mast, and Kenneth J. Leib	

Volume 2

E11.	Characterization of mainstem streams using water-quality profiles	543
	By Kenneth J. Leib, M. Alisa Mast, and Winfield G. Wright	
E12.	Trace elements and lead isotopes in modern streambed and terrace sediment—Determination of current and premining geochemical baselines	571
	By Stanley E. Church, David L. Fey, and Daniel M. Unruh	
E13.	Topographic, geophysical, and mineralogical characterization of geologic structures using a statistical modeling approach	643
	By Robert R. McDougal, Anne E. McCafferty, Bruce D. Smith, and Douglas B. Yager	
E14.	Formation and geochemical significance of iron bog deposits	689
	By Mark R. Stanton, Douglas B. Yager, David L. Fey, and Winfield G. Wright	
E15.	Ferricrete classification, morphology, distribution, and carbon-14 age constraints	721
	By Philip L. Verplanck, Douglas B. Yager, Stanley E. Church, and Mark R. Stanton	
E16.	Geomorphology of Cement Creek and its relation to ferricrete deposits	745
	By Kirk R. Vincent, Stanley E. Church, and Laurie Wirt	
E17.	Geochemical and hydrologic processes controlling formation of ferricrete	775
	By Laurie Wirt, Kirk R. Vincent, Philip L. Verplanck, Douglas B. Yager, Stanley E. Church, and David L. Fey	
E18.	Status of stream biotic communities in relation to metal exposure	823
	By John M. Besser and William G. Brumbaugh	
E19.	Toxicity of metals in water and sediment to aquatic biota	837
	By John M. Besser and Kenneth J. Leib	
E20.	Effects of mining on benthic macroinvertebrate communities and monitoring strategy	851
	By Chester R. Anderson	
E21.	Application of physical habitat simulation in the evaluation of physical habitat suitability	873
	By Robert T. Milhous	
E22.	Response of the upper Animas River downstream from Eureka to discharge of mill tailings	889
	By Kirk R. Vincent and John G. Elliott	
E23.	Effects of the May Day mine site on stream-water quality in the Cement Creek basin, August 2000	943
	By Winfield G. Wright, Briant A. Kimball, and Robert L. Runkel	
E24.	Using the OTIS solute-transport model to evaluate remediation scenarios in Cement Creek and the upper Animas River	973
	By Katherine Walton-Day, Suzanne S. Paschke, Robert L. Runkel, and Briant A. Kimball	
E25.	Processes affecting the geochemical composition of wetland sediment	1029
	By Mark R. Stanton, David L. Fey, Stanley E. Church, and Charles W. Holmes	
F.	Potential for successful ecological remediation, restoration, and monitoring	1065
	By Susan E. Finger, Stanley E. Church, and Paul von Guerard	
G.	Digital databases and CD-ROM for the Animas River watershed	1079
	By Tracy C. Sole, Matthew Granitto, Carl L. Rich, David W. Litke, and Richard T. Peltier	